Evaluation of Proposed Testing and Monitoring Activities at Carbon TerraVault's Monterey Formation A1-A2 Class VI Project

This testing and monitoring evaluation report for the proposed Carbon TerraVault (CTV)-Elk Hills Class VI geologic sequestration (GS) project summarizes EPA's review of the testing and monitoring the applicant proposes to conduct during and following injection operations into the Monterey Formation A1-A2 Sands. Due to the similarities of certain monitoring activities (e.g., groundwater monitoring and plume and pressure front tracking) to be performed in the injection and post-injection phases, these activities (as described in Attachments C and E of the Class VI permit application dated August 30, 2021, and Attachment E with information specific to well 355-7R submitted on December 3, 2021) are evaluated in a single report. This review identifies preliminary questions for the applicant, includes requests for supplemental information, and provides some considerations for future testing/analytical requirements. Note that, because of the interdependencies between the testing and monitoring strategy and other aspects of the permit application, additional questions may arise as other reviews proceed. This evaluation addresses both injection wells (Well 357-7R and Well 355-7R); specific evaluations unique to each well are detailed under "Injection Well Testing" below. CTV will need to prepare separate Testing and Monitoring Plans for each injection well if Class VI injection permits are issued.

CTV notes that they will report the results of all injection-phase testing and monitoring activities in compliance with the requirements of 40 CFR 146.91. All post-injection site care monitoring data and monitoring results collected using the methods described above will be submitted to EPA in annual reports submitted within 90 days following the anniversary date on which injection ceases.

Carbon Dioxide Stream Analysis

To meet the requirements of 40 CFR 146.90(a), CTV plans to analyze the carbon dioxide (CO_2) stream quarterly for the constituents identified in Table 1 of the Testing and Monitoring Plan, which is replicated below.

Parameter	Analytical Method(s)
Oxygen	ASTM D1945
Nitrogen	ASTM D1945
Carbon Monoxide	ASTM D1945
Total hydrocarbons	ASTM D1945
Methane	ASTM D1945
Hydrogen Sulfide	ASTM D1945/D6228
CO_2 purity	ASTM D1945
Total Sulfur	ASTM 3246

There are no EPA-approved analytical methods for CO_2 injection streams, and the methods listed on Table 1 are not included among EPA-approved wastewater analytical methods in 40 CFR Part 136 (nor are they used in other Class VI CO_2 injection permits). Many of the analytes are to be analyzed using

ASTM D1945, which is the Standard Test Method for Analysis of Natural Gas by Gas Chromatography. Based on the physical states of natural gas and CO_2, this test may be appropriate for CO_2 injectate analysis; however, no specific information or justification was provided in the application materials and there is no publicly available (free-of-charge) information available about these ASTM methods.

Table 4 of the Quality Assurance Surveillance Plan (QASP), Summary of Analytical Parameters for CO_2 Stream, also lists analysis of ethanol using method EPA 8260B. Although there is no EPA-approved analytical method for ethanol analysis in wastewater, this method is acceptable.

CTV is evaluating several sources of CO_2 as injectate for the project, and states that it will notify EPA prior to switching or adding CO_2 sources so that the sampling procedures can be reassessed. EPA will require that a sample be analyzed prior to initiation of injection.

CTV states that it will increase the sampling frequency if there is a significant change in the chemical or physical characteristics of the CO_2 injectate, a change in the CO_2 injectate source, or if the facility or injection well experiences a downtime over more than 30 days. Any change in the injection fluid would require advance notice and written approval from EPA.

Questions/Requests for the Applicant:

- *Please provide additional information on the ASTM methods listed in Table 1, including why CTV considers them to be appropriate for CO_2 injectate analyses. For example, ASTM D1945 is for the analysis of natural gas. Does the method clearly indicate that it can be used to analyze CO_2 injectate?*
- *Please update Table 1 to reflect that the analytical method for total sulfur is ASTM D3246 (the "D" is missing from the table).*
- *Please add analysis of ethanol using EPA method 8260B to Table 1 to be consistent with Table 4 of the QASP.*
- *Please add quarterly sampling of argon, hydrogen, oxides of nitrogen, ammonia, and δ13C to the list of analytes to fully characterize the CO_2 stream.*
- *Please also add H_2O as a CO_2 stream analyte on Table 1 to provide information about the presence of free phase water, as discussed in Attachment G.*
- *ASTM D3246 appears to have several available subparts for various substances to be tested; please specify the method to be used for sulfur analysis of the CO_2 injectate.*
- *Please clarify the year of all the ASTM methods (e.g., ASTM D3246-15) in Table 1.*
- *CTV states that quarterly sampling will begin three months after the date of authorization of injection; please revise this timeline to begin three months after the commencement of injection so that the testing schedule is consistent with injection operations.*

Considerations based on the results of Pre-Operational Testing/Modeling Updates:

- *EPA will require a baseline injectate sample be analyzed for the same parameters as in the Testing and Monitoring Plan prior to commencement of injection.*
- *If this sample or any updated information about injection formation fluids indicates that any injectate constituents may lead to geochemical reactions that could affect operations or change aquifer properties, additional analytical parameters for the injectate analysis may be requested.*

Injection Well Testing

The subsections below describe: the planned quarterly corrosion monitoring; continuous recording of injection pressure, rate, and volume to evaluate internal mechanical integrity; and annual external MITs that will meet the requirements at 40 CFR 146.90(b), (c), and (e). This portion of the testing and monitoring evaluation addresses both injection wells (Well 357-7R and Well 355-7R); however, CTV will need to provide a Testing and Monitoring Plan for each well, with unique well-specific testing (particularly for corrosion monitoring and continuous monitoring) that reflects each well's design.

Corrosion Monitoring

CTV proposes to conduct corrosion monitoring using the coupon method. The corrosion coupons will be in the pipeline that feeds CO_2 injectate to the injectors. Corrosion monitoring will occur between the compressor and wellhead, according to Table 1 of the QASP.

Samples of the materials used in the construction of the pipeline and injection well that are exposed to CO_2 injectate will be monitored for corrosion using corrosion coupons. Representative materials will be weighed, measured, and photographed prior to installation. The coupons will be sent to a lab and photographed, measured, visually inspected, and weighed to a resolution of 0.1 milligram. The specific methods by which the samples will be handled are not described in the testing and monitoring plan; however, Table 5 of the QASP indicates that analytical methods include NACE TM0169/G31 and EPA 1110A SW846.

CTV says that, if the corrosion rate is greater than 0.3 mils/year, it will initiate consultation with regulatory agencies (in this case EPA), and may run a casing inspection log to assess the thickness and quality of the casing.

The proposed coupons will be composed of the materials summarized in Attachment C, Table 3. The materials identified for corrosion monitoring were compared to the list of proposed construction materials for the injection well in Attachment G (Construction details) for Well 357-7R (submitted with the initial permit application on August 30, 2021) and Well 355-7R (submitted December 2, 2021). The first two columns of the table below are adapted from Table 3 of the Testing and Monitoring Plan (list of equipment coupon with material of construction), with review notes in the right-hand columns.

Coupon (Attachment C, Table 3)	**Construction Material (Attachment C, Table 3)**	**Review Notes based on Information in Attachment G**	
		Well 357-7R	**Well 355-7R**
Pipeline	CS A106B	Not identified	Not identified
Casing	N80 Steel	Intermediate and Long-string: N80 (pg. 2)	Intermediate and Long-string: N-80, K-55 (Table 5)
Tubing	13 CR-95	13 CR-95 (pg. 2)	L-80 (Table 6)
Wellhead	Stainless steel	Not identified	Not identified

The coupons proposed for corrosion monitoring of the casing and tubing match those described in Attachment G for injector 357-7R. However, it appears that Well 355-7R has different construction, and a corrosion testing program specific to the 355-7R injector is needed. Although the materials of

construction for the pipelines and wellheads are not described in Attachment G, it is assumed that coupons would be selected to represent these materials.

Questions/Requests for the Applicant:

- *Please describe the corrosion coupons for a corrosion testing program specific to the 355-7R injector.*
- *Please clarify that CTV will discuss any detected corrosion rate of more than 0.3 mils/year with EPA.*
- *For completeness, please include the details about the analytical methods for corrosion coupon monitoring that are described in Table 5 of the QASP into the Testing and Monitoring Plan.*
- *Please provide the list of construction materials to be used for the pipeline and wellhead so that they can be compared to the proposed coupon materials for the corrosion testing program.*
- *Under "monitoring details," Attachment C says that the coupons will be sent to a lab for analysis every 6 months. Corrosion monitoring must be performed on a quarterly basis, per 146.90(c); please revise the Testing and Monitoring Plan accordingly.*

Continuous Monitoring to Evaluate Internal Mechanical Integrity

CTV will install and use continuous recording devices to monitor: injection pressure, rate, and volume; the pressure on the annulus between the tubing and the long string casing; the annulus fluid volume added; and the temperature of the CO_2 stream, as required by 40 CFR 146.88(e)(1), 146.89(b), and 146.90(b).

Surface injection pressure will be set to a minimum of 1,200 psi, eventually reaching 2,000 psi at the cessation of injection operations, as noted in the discussion of "Operational Procedures" in the permit application narrative. For Well 357-7R, the surface and downhole pressure gauges will ensure the maximum allowable injection pressures of 3,800 psi (surface) and 6,100 psi (downhole) are not exceeded. For Well 355-7R, the surface and downhole pressure gauges will ensure the maximum allowable injection pressures of 2,900 psi (surface) and 6,108 psi (downhole) are not exceeded.

Additionally, a surface pressure gauge will be installed on the annulus to monitor the annular pressure and ensure the integrity of the packer and tubing. However, the annular pressure needed to signify a mechanical integrity issue is not indicated by CTV.

The maximum injection rate of 30 million standard cubic feet per day (mmscfpd) and average injection rate of 10-15 mmscfpd will be monitored by a surface flowmeter. The calculation of injection volumes will be calculated using the injection flow rate and CO_2 stream density and will be used to ensure the maximum expected injection volume does not exceed 10 million tonnes.

Temperature gauges will be employed at surface and downhole to monitor the temperature of the injectate and ensure it is consistent with the expected temperature of the CO_2 stream at a given depth. Additional evaluation of the well monitoring equipment will be provided in the Well Construction reports for the injection wells.

Table 2 of Attachment C lists sampling devices, locations, and frequencies for continuous monitoring and is replicated below.

Parameter	Device(s)	Location	Min. Sampling Frequency	Min. Recording Frequency
Injection pressure	Pressure Gauge	Surface and Downhole	30 seconds	30 seconds
Injection rate	Flowmeter	Surface	30 seconds	30 seconds
Injection volume	Calculated	Surface	30 seconds	30 seconds
Annular pressure	Pressure Gauge	Surface	30 seconds	30 seconds
CO_2 stream temperature	Temperature gauge	Surface and Downhole	30 seconds	30 seconds

Questions/Requests for the Applicant:

- *Please clarify the location/depths of the downhole temperature and pressure gauges listed on Table 2. These should also be depicted on the well schematics.*
- *Please add monitoring of the annulus fluid volume to Table 2 to match the activities required at 40 CFR 146.90(b).*
- *Please explain the appropriateness of a 30 second minimum sampling and recording frequency versus at a higher frequency (e.g., 10 seconds).*
- *Please explicitly define the annular pressure deviation that would warrant a mechanical integrity investigation.*

Considerations based on the results of Pre-Operational Testing/Modeling Updates:

- *The maximum pressure thresholds identified for continuous monitoring and the annulus pressure in Attachment C may need to be adjusted to reflect the final permit conditions (e.g., if they change based on the results of pre-operational testing).*

External MITs

To verify external mechanical integrity as required at 40 CFR 146.89(c) and 146.90, CTV proposes to perform MITs annually. CTV also proposes to perform these same MITs prior to commencing injection.

Table 6 of Attachment C lists the MITs to be performed and is reproduced below.

Test Description	Location
Temperature Log	Along wellbore via wireline well log
Radioactive Tracer Survey (RTS)	Along wellbore via iodine

On page 9 of Attachment C, CTV only indicates that it will run a temperature log (and not a radioactive tracer log) and notes that if it elects to conduct an alternate MIT, it will request approval from EPA. (EPA notes that, if CTV opts to use an alternative MIT, the Class VI permit would need to be modified to incorporate this test.) CTV presents procedures for MIT temperature logging but does not describe the radioactive tracer logging procedures.

Questions/Requests for the Applicant:

- *Please revise the temperature logging procedure to include a minimum of 4 hours between runs. Additionally, please provide more extensive temperature logging procedures, e.g., in accordance with the document, "Appendix E – Temperature Logging Procedures – U.S.E.P.A. Region IX," which is available online at: https://archive.epa.gov/region9/water/archive/web/pdf/appendixetemplogreqs.pdf.*
- *Please provide a detailed description of the MIT testing procedures for RTS.*
- *CTV states that MITs will be performed annually, within 30 days of the injection authorization date. Please revise this timeline to coincide with the commencement of injection so that the testing schedule is consistent with injection operations.*
- *Table 6 describes the location of the RTS to be "along wellbore via iodine" it is assumed that this refers to the specific tracer to be used. Please clarify and edit the table to read "along wellbore via iodine tracer," if appropriate.*
- *The Emergency and Remedial Response Plan includes scenarios for monitoring well MI failures, however no MIT of the monitoring wells is described in the Testing and Monitoring Plan. Please provide procedures and plans for performing MITs in the deep monitoring wells.*
- *Please include MITs on the monitoring wells and the EOR wells to be used for deep monitoring as part of the Testing and Monitoring Plan.*
- *Attachment G describes Annulus Pressure Testing Procedures for Monitoring Well 327-7R-RD1 & 342-7R-RD1. Please also include internal and external MITs during the injection and post-injection phases and describe these in Attachments C and E.*

Pressure Fall-Off Testing (PFOT)

CTV states that it will perform pressure fall-off tests during the injection phase to meet the requirements of 40 CFR 146.90(f). However, the attachment also says that "CTV does not currently plan to complete pressure fall off testing" (pg. 10), given the extent of available information about the Monterey Formation A1-A2 Sands. CTV says that it will consider pressure fall-off testing if the injection rate decreases, with a simultaneous injection pressure increase outside the results of computational modeling. A pressure fall-off test must be performed prior to injection and at least once every 5 years, per the Class VI Rule.

Attachment C also provides a brief description of PFOT procedures.

Questions/Requests for the Applicant:

- *Please clarify in the Testing and Monitoring Plan that a pressure fall-off test will be performed every 5 years during the injection phase, as required by 40 CFR 146.90(f).*
- *Please provide more detailed PFOT procedures, e.g., in accordance with the document, "EPA Region 9 UIC Pressure Falloff Requirements," which is available online at: https://archive.epa.gov/region9/water/archive/web/pdf/falloff-testing-guidlines.pdf.*

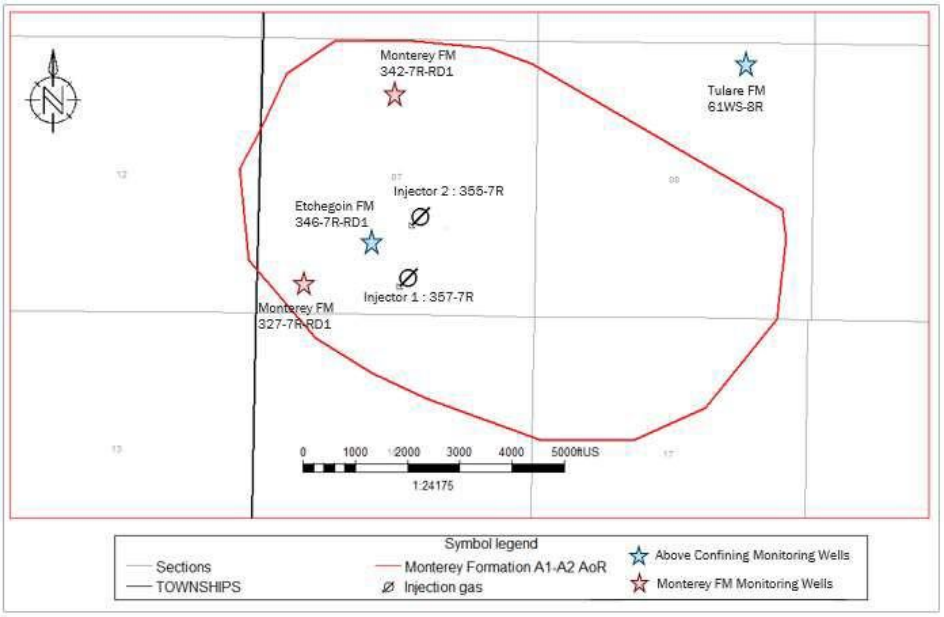
Groundwater Quality Monitoring

CTV proposes to monitor groundwater quality in existing wells above the confining zone using direct and indirect methods. To meet the requirements of 40 CFR 146.90(d), CTV proposes to perform the following monitoring above the confining zone:

- Annual injection-phase water quality monitoring and continuous pressure and temperature monitoring via one well located outside of, and to the northeast of, the delineated AoR in the Upper Tulare Formation (the lowermost USDW) and the Lower Tulare Formation. Post-injection water quality sampling will continue annually and continuous pressure monitoring in the USDW is proposed.
- Continuous monitoring of pressure and temperature in the Etchegoin Formation within a monitoring well located to the west of the injection wells.

Attachment E does not describe any monitoring in the Etchegoin or the Monterey Formation A3-A11 Sands after cessation of injection. However, EPA will likely require that post injection phase monitoring be an extension of injection phase monitoring to confirm continued demonstration that USDWs are not endangered and to inform the non-endangerment demonstration required at 40 CFR 146.93(b)(3).

Figure 2 of the QASP shows the locations of all monitoring wells associated with the project and is reproduced below.



The Etchegoin Formation monitoring well appears to be situated within the AoR and in the anticipated path of the CO_2 plume and pressure front (based on information in Attachment B). The Upper/Lower Tulare Formation monitoring well is outside of the delineated AoR to the northeast of the injection wells, and down plume. Given that the Tulare Formation does not hold much water within the AoR, this location, while not in the same direction as the deeper monitoring wells may be most appropriate to allow geochemical sampling, although it is unlikely that CO_2 will travel that far down the limb of the anticline. CTV states that additional Upper Tulare monitoring wells will be drilled if increased pressure is observed in the Etchegoin Formation monitoring well or water quality changes in the Tulare Formation that is due to Monterey Formation A1-A2 CO_2 injection. However, it is unclear how a linkage of water quality/pressure changes to CO_2 injection (and not other activities) would be made.

The applicant proposes to monitor water quality in the Upper/Lower Tulare Formation and the Monterey Formation during the injection and post-injection phases. The analytical and field parameters and methods described in Tables 5 and 8 of Attachment C (injection-phase monitoring of the Tulare and Monterey Formations, respectively) are nearly the same as those in Tables 2 and 5 of Attachment E. Additional information about monitoring in the Monterey Formation is described under "CO_2 Plume Tracking" below. CTV also proposes to perform a baseline water analysis in the Etchegoin Formation monitoring zone and in the Tulare Formation monitoring well.

Table 5 of Attachment C (Injection-phase Tulare Formation monitoring) is reproduced in the first two columns of the table on the next page. Because consistency of monitoring parameters above and within the injection zone is appropriate for detecting leakage of the CO_2 plume, EPA evaluated proposed injection and post injection monitoring in the Tulare and Monterey Formations together. EPA's notes and recommendations are provided in the right-hand column; see also the discussion of "Quality Assurance Procedures" below for additional comments on the parameters to be monitored.

The parameters appear to be generally appropriate for groundwater quality monitoring needs for GS projects, and are consistent with other Class VI monitoring programs, except as noted below. As the permit application narrative describes (pg. 39), the Monterey A1-A2 Sands are dominated by quartz and feldspar, which are stable in the presence of CO_2 and carbonic acid. Note that, as additional information is gathered based on the reviews of other parts of the permit application or pre-operational data collection, recommendations or requirements for additional analytical parameters may be provided.

Parameters	Analytical Methods	Evaluation Notes/Recommendations
Tulare Formation		
Cations (Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Se, Tl)	ICP-OEC EPA 200.7/6010B	200.7 and 6010B are both ICP-AES methods, not ICP-OEC. Please explain what ICP-OEC is or revise the table. In Table 17 of the QASP, the final cation is Ti, not Tl as in Attachment C. Please clarify/be consistent. Also, this is "T1" in the tables of Attachment E; please correct the typographical error. Cations of Sb are also mentioned in Table 17 of the QASP; please add this to the ground water monitoring parameters in Attachments C and E. 200.7 is an EPA-approved wastewater analytical method, while 6010B is not. EPA requests that Method 200.7, Rev 4.4 (1994) be specified.
Cations (Ca, Fe, K, Mg, Na, Si)	ICP-OEC EPA 200.7/6010B	See above.
Anions (Br, Ca, F, NO3, SO4)	Ion Chromatography, EPA Method 300.0	Attachment E and Table 17 of the QASP also include anions of Cl; please add this to Attachment C for consistency and completeness. Tables 2 and 5 of Attachment E reference EPA Method 300; please revise the method to be consistent with Attachment C (i.e., Method 300.0). Also, please specify that EPA Method 300.0, Rev. 2.1, Part A (1993) will be used.
Dissolved CO_2	SM 4500-CO2-C	No comments.
Total Dissolved Solids	SM 2540 C	Attachment E refers to SM 4500 C for TDS; EPA requests the use of SM 2540 C for consistency.
Alkalinity	SM 2320 B	Attachment E refers to SM 2510, which is for conductivity, not alkalinity. EPA requests that CTV revise Attachment E to reference SM 2320 B for consistency. (SM 2320 B is an approved wastewater method.)
pH (field)	EPA 150.1 / SM4500-H+B	No comments.
Specific Conductance (field)	SM 2510 B	SM 2510 B is named by SM as a laboratory method, and it is not clear whether SM 2510 B can be conducted in the field. EPA Method 120.1 may be more amenable to field screening if SM 2510 B is not. Please clarify if field use of SM 2510 B is possible or revise the table (i.e., field vs. lab designation) or the method.
Temperature (field)	Thermocouple	No comments.
Dissolved Methane	RSK-175/Gas Chromatography	This method was developed by EPA but is not an EPA approved method for wastewater analysis. Please provide information to support the use of this method for dissolved methane analysis. Alternatively, consider using EPA-approved method SM 6211 B and/or 6211 C.

EPA recommends in Class VI guidance that monitoring well construction and planned plugging procedures for monitoring wells be reviewed as part of the permit application evaluation to confirm that

these wells will not provide conduits for fluid movement that could endanger USDWs. No monitoring well construction or plugging information was provided in the permit application materials.

CTV should note that the Central Valley Water Board indicated in its consultations with EPA on a prior Class VI project that any newly drilled monitoring wells must be approved by the Water Board and, while existing wells would not need to be approved, the Water Board expressed interest in any plans to use existing wells as monitoring wells.

Attachment C also describes the water quality sampling procedures, the laboratory to be used, and chain of custody procedures. This information is detailed in the QASP as well.

Questions/Requests for the Applicant:

- *Please update Tables 5 and 8 of Attachment C and Tables 2 and 5 of Attachment E as noted in the table above. Further, the same analytes and methods should be used for monitoring of all formations - to provide consistent data to support modeling reviews and a non-endangerment demonstration.*
- *In addition, please include additional ground water quality parameters to support a robust monitoring program, as follows:*
    - *δ13C, which is mentioned in the QASP, but not in Attachments C and E.*
    - *Water density (which is referenced in the Testing and Monitoring Plan as an expected water quality change due to plume movement on pg. 12).*
    - *Dissolved O_2 and H_2S. Dissolved O_2 is a primary indicator of water quality. H_2S occurs in the subsurface, may be common in oil fields, and has the potential to be mobilized, and, is listed as a toxic substance by the CDC.*
- *Please include sampling/measurement depths in Table 4 of Attachment C and Table 1 of Attachment E for clarity and completeness.*
- *Table 4 of Attachment C indicates that CTV will perform pressure and temperature monitoring in the Tulare Formation, but Table 1 of Attachment E indicates that only pressure monitoring is planned. Please revise Attachment E to be consistent or explain why temperature monitoring will not continue in the post-injection phase.*
- *Please include quarterly (rather than annual) water quality monitoring during the injection phase to: confirm that the CO_2 is being confined, help validate modeled predictions, and eventually support the non-endangerment demonstration.*
- *Please add water quality monitoring of the Etchegoin Formation - to provide earlier warning of water quality changes than would be identified in the Tulare Formation monitoring well.*
- *Please explain the appropriateness of a single Tulare Formation monitoring well location relative to the anticipated direction of plume and pressure front movement, and, given the size of the injection operation. Additionally, please confirm that the predominant groundwater flow direction in the Tulare Formation is easterly. If flow direction is not easterly, provide an updated groundwater well monitoring plan that includes appropriate well placement in relation to groundwater flow direction.*
- *Please provide schematics of all the wells to be used for monitoring that depict the sampling equipment/gauges to be used, and their depths, including the EOR wells (to be used for plume tracking), and the sampling at two depths in the Tulare Formation monitoring well.*
- *Please also provide plugging and abandonment plans for all the monitoring wells.*

- *Attachment C states that pressure and temperature monitoring in the Etchegoin Formation is planned at 3,828 feet TVD, which is significantly shallower than the Reef Ridge Shale confining zone (at 6929 feet, per the permit application narrative). Please explain how monitoring at this depth will provide early indication of pressure changes above the confining zone.*
- *Please include post-injection pressure and temperature monitoring in the Etchegoin Formation to Attachment E.*
- *Please describe post-injection monitoring in the Tulare Formation well that continues the injection-phase monitoring, including post-injection monitoring in the Lower Tulare Formation and continuous temperature (in addition to pressure) monitoring.*
- *The PISC and Site Closure Plan states (on page 4) that sampling in the Tulare Formation will occur every 5 years, and Table 1 lists the Tulare Formation fluid sampling frequency as annual. Please revise the text to match Table 1.*
- *The Testing and Monitoring Plan states, on page 7, that additional Tulare Formation monitoring wells would be drilled if pressure or composition changes due to CO_2 injection are detected. Please describe how this linkage to CO_2 injection would be made.*
- *Please include the groundwater monitoring well 61WS-8R in Figure 4 of the PISC and Site Closure Plan.*
- *Is Zalco laboratory a state-certified laboratory? Please note that EPA's Class VI UIC guidance recommends use of a laboratory that is state-certified.*

Considerations based on the results of Pre-Operational Testing/Modeling Updates:

- *If new information or updates to the geochemical modeling based on pre-operational testing raises additional concerns about subsurface geochemical processes (e.g., potential changes in subsurface properties or potential contaminant mobilization), the list of groundwater quality analytical parameters may need to be updated to ensure that all applicable parameters are included.*

CO_2 Plume and Pressure Front Tracking

The applicant describes proposals for CO_2 plume and pressure front tracking that include: (1) the use of direct and indirect methods for tracking the pressure front within the injection zone [40 CFR 146.90(g)(1)]; and, (2) direct pressure front monitoring in two monitoring wells and seismic monitoring to indirectly track the extent of the CO_2 plume [40 CFR 146.90(g)(2)].

For post-injection site care, CTV will employ direct and indirect methods to track the extent of the carbon dioxide plume and the presence or absence of elevated pressure. In Attachment E, Table 4 details the methods that will be used to monitor the CO_2 plume post-injection, and Table 6 details the methods that will be used to monitor the associated pressure front. Injection reservoir pressure monitoring will occur to ensure confinement of the reservoir and consistency with computational modeling results. As seen in Table 6 of Attachment E, seismicity monitoring will also occur via surface and shallow borehole seismometers. Table 5 of Attachment E lists the analytical methods that will be used for the injection zone fluid monitoring and analysis.

CO_2 Plume Monitoring

CTV proposes to monitor the plume via direct and indirect monitoring in the Monterey Formation:

Direct plume tracking methods include:

- Annual fluid sampling during the injection and post-injection phases in Monterey Formation A1-A2 Sands via two monitoring wells (327-7R-RD1 and 342-7R-RD1, located to the southwest and the northwest of the injection well, respectively).

- Quarterly fluid sampling during the injection phase in EOR producers in the Monterey A3-A11 Sands. The location of the EOR wells is not described.

Indirect plume monitoring includes:

- Pulse neutron logging in the Monterey Formation A1-A2 Sands via the same monitoring wells. This logging will be conducted every two years during the injection phase and every 5 years during the post-injection phase.

The parameters and associated analytical methods are presented in Table 8 of Attachment C. They are identical to those proposed for Tulare Formation water quality monitoring described under "Ground Water Monitoring" above. Deep and shallow water quality monitoring should be for the same parameters to provide consistent data on which to evaluate potential fluid movement out of the confining zone.

Figure 2 of the QASP (reproduced under "Groundwater Monitoring" above) shows the location of the monitoring wells in the Monterey Formation A1-A2 Sands. CTV asserts that modeling indicates that the CO_2 plume will reach each of these monitoring wells by the second year of injection.

Pressure Front Monitoring

CTV plans to conduct **direct pressure front monitoring** by continuously monitoring pressure and temperature during the injection and post-injection phases within the Monterey Formation A1-A2 Sands via pressure gauges in monitoring wells 327-7R-RD1 and 342-7R-RD1.

Indirect pressure front monitoring will be accomplished via seismic monitoring throughout the AoR. CTV states that it will monitor seismicity with surface and shallow borehole seismometers it plans to install, as well as monitor seismic data from the Southern California Earthquake Data Center (SCEDC) network. This continuous monitoring will continue throughout the injection and post-injection phases.

Pressure-front monitoring activities are summarized in Table 9 of Attachment C and Table 6 of Attachment E.

Questions/Requests for the Applicant:

- *Please refer to EPA's questions and recommendations under "Groundwater Monitoring" above regarding water quality analysis and revise Table 8 of Attachment C and Table 5 of Attachment E accordingly.*
- *Please edit Table 8 to refer to the Monterey Formation, rather than the Tulare Formation to reflect monitoring in the A3-A11 Sands.*
- *Please elaborate on the monitoring in the Monterey Formation A3-A11 Sands as described on page 12 of Attachment C. Specifically, where are the EOR producers from which CTV plans to sample the Monterey Formation A3-A11 Sands? At what depths will sampling be performed, and what parameters will be analyzed for? (The analytical parameters should be consistent with other monitoring.) Please describe who owns these wells, and whether they will be operational throughout the injection and post-injection periods? Please include the locations of these wells on the relevant figures in Attachments C and E and the QASP.*
- *Please describe the seismic monitoring network discussed on pg. 16 of Attachment C, including the number and location of the seismometers that CTV proposes to install.*
- *Please explain the timeframe for which a seismicity baseline will be established, and if historical seismicity will be incorporated into this baseline.*
- *Page 15 of Attachment C says that CTV plans to perform direct pressure monitoring in the Monterey Formation A1-A2 Sands, and Table 9 indicates that pressure and temperature monitoring will be performed. Please revise the statement on pg. 15 to be consistent with the table – to include temperature as well as pressure.*
- *EPA recommends that the sampling/measurement depths be included in Tables 7 and 9 of Attachment C and Tables 4 and 6 of Attachment E for clarity and completeness.*
- *Attachment C states (pg. 11) that, if plume development is not consistent with modeling results, CTV will assess whether additional monitoring of the plume is necessary. Please clarify in the plan that this determination would be made in consultation with the UIC Program Director and that this would trigger an AoR reevaluation, per the AoR and Corrective Action Plan.*
- *Please make the following changes to the proposed plume and pressure front tracking in Attachments C and E:*
    - *Perform frequent sampling and logging (e.g., quarterly, or semi-annually) early in the injection phase (i.e., at least until the CO_2 plume passes the monitoring well locations). This would allow the acquisition of additional data to validate the modeling, provide early warning of unanticipated fluid movement, and be consistent with other Class VI projects.*
    - *Conduct a 3D seismic survey or a vertical seismic profile during injection operations for comparison to the 2019 3D seismic survey described in the application narrative.*
    - *Conduct quarterly water quality sampling in the A1-A2 Sands for plume tracking to be consistent with the A3-A11 monitoring activities as well as provide additional data points to validate modeled predictions, and to eventually support the demonstration of non-endangerment.*

Air/Soil or Other Testing and Monitoring

Based on the currently available information about the geologic setting (i.e., the depth of the injection formations and the lack of evidence for the presence of transmissive faults of fractures), surface air and/or soil gas monitoring are not needed to detect movement of fluid that could endanger USDWs within the AoR.

Considerations based on the results of Pre-Operational Testing/Modeling Updates:

- *If, based on the results of planned pre-operational testing, uncertainties about the geologic setting are identified, the need for air and/or soil gas monitoring or other monitoring will be reconsidered.*

Quality Assurance Procedures

The review team evaluated the QASP submitted with the permit application to verify that all the testing activities, analytes, etc., included in the QASP are consistent with proposed injection and post-injection phase testing and monitoring. All the injection and post-injection testing and monitoring activities (except for pressure falloff testing) are addressed in the QASP and the QASP covers activities recommended by EPA. EPA noted a few discrepancies between the tables in the QASP and the activities described in Attachments C and E. These are summarized in the table below:

QASP Table	**EPA comments**
Table 1. Summary of testing and monitoring.	Cement bond logs and standard annulus pressure tests of the injection wells are listed in the QASP, but these tests are not described in Attachment C. Please clarify if these tests are planned to be performed, either as part of pre-operational or injection-phase testing, or revise the QASP accordingly. Please add PFOT and RTS to Table 1.
Table 2. Monitoring Well Summary.	Monitoring the A3-A11 Sands via the EOR wells is not included on Table 2 of the QASP; please include this for consistency.
Table 3. Summary of analytical and field parameters for ground water samples.	Please update the placeholders for specific cations and anions in Table 3 to reflect Table 17 of the QASP. This table should address sampling in formations other than the Tulare Formation (per recommendations above). There is a typo in the pH (field): the method “SPA 150.1” should be “EPA 150.1”
Table 5. Summary of Analytical Parameters for Corrosion Coupons.	Please include the QC Requirements on Table 5.
Table 17. Summary of sample containers, preservation treatments, and holding times for ground water samples.	There are a few discrepancies between the analytical parameters mentioned on Table 17 of the QASP and in Attachments C and E. EPA recommends the following changes for consistency: • Please revise the parameter NO_2 in Table 17 of the QASP to be consistent with NO_3, which is a planned analyte, per Attachments C and E.

QASP Table	EPA comments
	• Add cations of K (in Tables 5 and of Attachment C and Tables 2 and 5 of Attachment E) to Table 17. • Please also make other necessary revisions to Table 17 of the QASP to address EPA's requests related to analytical parameters under "Ground Water Monitoring" above.
Other	Please fix the formatting of the Table of Contents for Section B.1. a.